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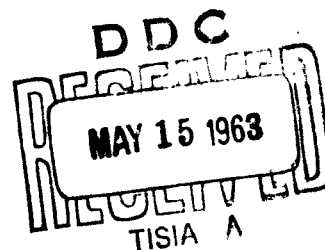
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CALORIMETRIC MEASUREMENTS OF
GAMMA RAY, FAST NEUTRON, AND
CHARGED PARTICLE ABSORBED DOSES

by
E. R. Schleiger
N. Goldstein
E. Tochilin

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U.S. NAVAL RADIOLOGICAL
DEFENSE LABORATORY
SAN FRANCISCO 24, CALIFORNIA

12ND. P7463

RADIOLOGICAL PHYSICS BRANCH
E. Tochilin, Head

NUCLEONICS DIVISION
W. E. Kreger, Head

Eugene P. Cooper
Scientific Director

E. B. Roth, CAPT USN
Commanding Officer and Director

ABSTRACT

The energy absorbed by aluminum, carbon, or tissue-equivalent (TE) material when exposed to gamma rays, fast neutrons, or 900-Mev alpha particles was measured with a microcalorimeter. The instrument was patterned after the one described by Reid and Johns, Rad. Res. 14, 1 (1961), but has an ethylene glycol bath instead of water. Spaced mylar sheets about 6-1/2 in. in diameter were mounted on one side of the absorber inside the evacuated cylindrical chamber in order that the detector could be thermally insulated in the direction of the beam without the presence of bath solution.

Gamma-ray absorbed dose rates as low as 2 rads/min were measured with the instrument. The dose rates obtained from the exposures to Co^{60} and Cs^{137} sources at this Laboratory (NRDL) agreed with the output of the sources as measured with a National Bureau of Standards secondary standard cavity ionization chamber. Thirteen 10-min exposures of the TE absorber in the microcalorimeter to fast neutrons from the University of California 60-in. cyclotron at Crocker Laboratory resulted in absorbed dose measurements varying from 24 to 40 rads. The average absorbed dose value was 5 percent higher than the NRDL determination based on flux and spectrum measurements. Microcalorimeter exposures to the 900-Mev alpha particle beam from the University of California 184-in. synchro-cyclotron at Lawrence Radiation Laboratory gave absorbed doses that agreed reasonably well with ionization chamber determinations.

SUMMARY

The Problem

The purpose of this experiment was to build and test a calorimeter capable of detecting temperature changes corresponding to absorbed energy rates of 2 rads/min in aluminum, carbon, and tissue-simulating absorbers when exposed to gamma rays, fast neutrons, or charged particles.

The Findings

The calorimeter was constructed and its use as a laboratory standard was demonstrated. Cs^{137} gamma-ray absorbed dose rates of 2 rads/min were measured by the instrument. Co^{60} and Cs^{137} gamma-ray dose rates agreed with ionization chamber measurements. Fast neutron absorbed dose rates with the tissue-simulating absorber were slightly higher than the dose rate based on spectrum and flux measurements. Calorimeter and ionization chamber measurements of 900-Mev alpha particle absorbed doses were comparable for dose rates varying from 75 to 4000 rads/min.

INTRODUCTION

Measurement of the temperature rise of irradiated material provides a fundamental and direct method of determining absorbed dose. The advantages of this technique have been demonstrated in earlier investigations and have led to the recommendation that calorimetry measurements be used for primary standardization of absorbed dose for photon energies above 1.0 Mev.[1,2]

The unit of absorbed dose is the rad. One rad is 100 ergs/g or 2.39×10^{-6} cal/g of absorbing material. For graphite, 1 rad of absorbed energy results in a temperature change of 1.4×10^{-5}°C. This paper describes a microcalorimeter designed to measure neutron and gamma-ray absorbed dose rates as low as 2 rads/min and evaluates its performance with various absorber materials and radiation sources. Aluminum, graphite, and tissue-equivalent (TE) material were used as absorbers. Dose rates for the absorbers obtained from gamma-ray exposures to Co^{60} and Cs^{137} sources at this Laboratory (NRDL) are compared to the outputs of the sources as measured with a National Bureau of Standards secondary standard cavity ionization chamber.

Doses of fast neutrons from the University of California 60-in. cyclotron at Crocker Laboratory were measured with the microcalorimeter using the TE absorber. Modified Sievert ionization chambers and film detectors gave comparative values with and without the equipment for fast neutrons and gamma rays. The microcalorimeter absorbed dose value is compared to the NRDL calibration based on flux and spectrum determinations and to measurements made with a system of homogeneous ionization chambers by the Radiobiological Research Unit of the Medical Research Council, Harwell, England. Results are also presented of higher dose rate exposures of the TE absorber to 900-Mev alpha particles from the University of California 184-in. synchro-cyclotron at Lawrence Radiation Laboratory.

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EXPERIMENTAL ARRANGEMENT

The calorimeter is of the conventional design consisting of a cylindrical absorber placed inside a concentric baffle which in turn is suspended in a vacuum chamber. The entire assembly is placed in a liquid bath which is held at a constant temperature so that steady-state conditions can be reached by the absorber, baffle, and vacuum chamber. Supplementary equipment includes the temperature sensor in the absorber and its related circuits, electrical heating coils and associated circuits for calibration purposes, the vacuum system, and the temperature controls for the bath. The following paragraphs describe the equipment in detail.

Vacuum Chamber and Bath

The general arrangement of the calorimeter, which is shown in Fig. 1 and 2, is similar to that used by Reid and Johns[1] and Bernier, et al.,[2] with the exception that one end of the aluminum vacuum chamber extends through the wall of the bath so that the incident radiation will not be attenuated by the bath liquid. Heat exchange between the absorber and the room through this extended end of the vacuum chamber was minimized by 14 aluminized mylar film radiation shields within the vacuum chamber and a 2-in. thick styrofoam plug over the outer end. Ethylene glycol was used as a bath liquid to minimize corrosion. The bath temperature was maintained by a mercury thermoregulator controlling an immersion heater. Operation of the bath at about $5^{\circ}C$ above average room temperature eliminated the necessity of a cooling system as the heat input from the stirring device and vacuum pump was more than compensated for by the losses from the bath to the surrounding atmosphere. Under these conditions, the bath temperature cycle had an amplitude of about $0.005^{\circ}C$.

A vacuum of approximately 10^{-5} mm of mercury was maintained by use of an ion pump which required a mechanical fore pump only during the initial pumping-down period. With this vacuum, the rate of heat
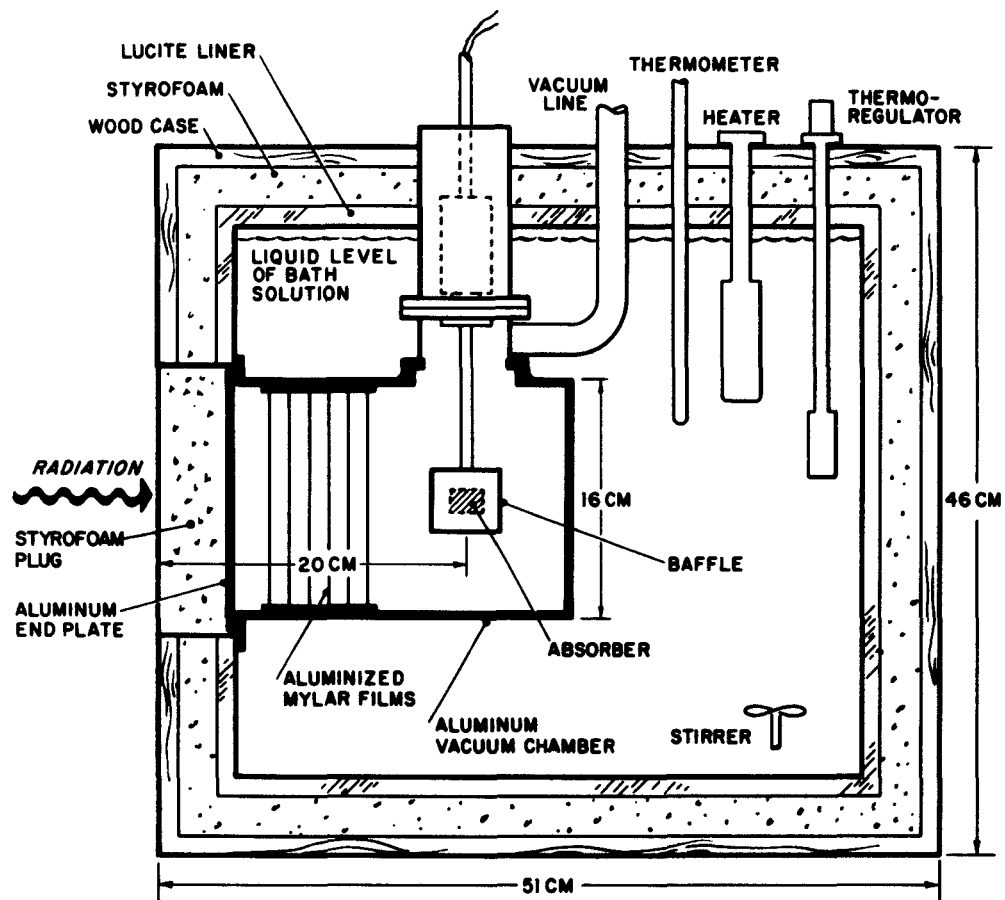
Fig. 1 A schematic drawing of the general arrangement of the microcalorimeter.
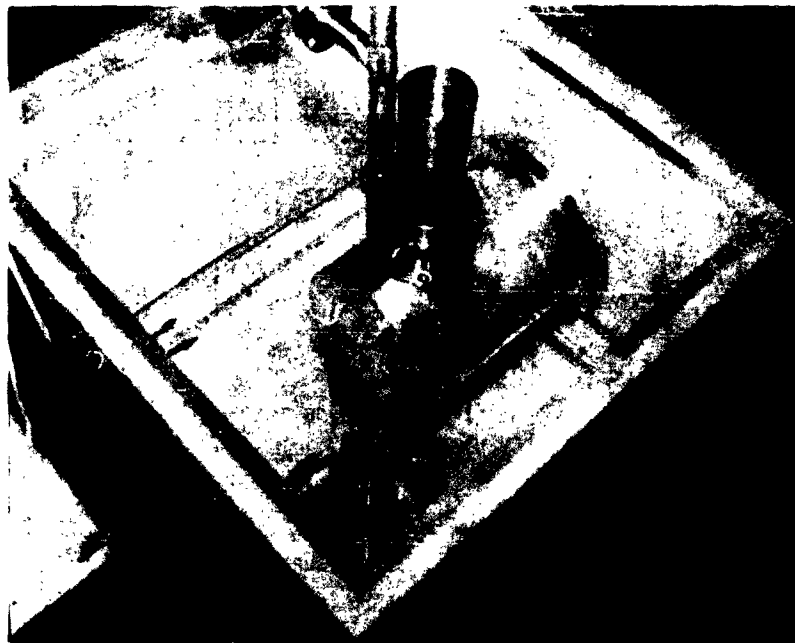
Fig. 2 The microcalorimeter with the top removed and the bath solution drained. The absorber assembly is attached to the standpipe that is bolted to the aluminum vacuum chamber.

exchange between absorber and bath was estimated to be of the order of 4×10^{-5} cal/°C per sec. This estimate was based on a measurement of the rate of temperature change of the graphite absorber for a known temperature difference (approximately 0.5°C) between bath and absorber.

Absorbers and Baffles

Absorbers were constructed of three different materials--aluminum (Al), graphite (C), and a tissue-equivalent carbon-loaded plastic (TE). The Al and C absorbers were in the form of a hollow cylinder. The TE absorber was a solid cylinder. Dimensions and weights of the absorbers are shown in Table 1. Electrical heating of the absorbers for calibration purposes was accomplished in the case of the Al and C absorbers by a coil of resistance wire which was wrapped around the outside of the cylinder in a helical groove. On the TE absorber the heating current was passed through the absorber material itself, electrical contact being made to a thin film of aluminum evaporated on each end of the cylinder. To minimize radiative losses from the absorber and heating coils, the absorber surfaces were covered by anodized aluminum foil, the anodized surface facing inward to prevent electrical shorting of the heating circuit.

Table 1

Absorber Data

Absorber Material	Weights (g)			Dimensions (cm)			Calibration Resistance (ohms)
	Absorber Material	Additional Material	Total	Diameter	Height	Wall Thickness	
Al	6.58	0.03	6.61	2.0	1.5	0.20	306
C	3.51	0.08	3.59	1.5	1.25	0.30	169
TE	5.10	0.20	5.30	2.0	1.5	solid	430 (approx.)

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Each absorber was suspended by nylon threads in a hollow baffle made of the same material as the absorber. Although the primary purpose of the baffle was to provide electronic equilibrium during irradiation, it served the additional purpose of making the absorber temperature changes nearly adiabatic during an exposure to radiation. Since the baffle absorbed energy from the radiation at the same rate as the absorber, it therefore experienced temperature changes of approximately the same magnitude. The baffles were also equipped with heating coils so that during calibrations the same electrical power per mass of baffle material could be supplied to the baffle as was supplied to the absorber. Figure 3 shows the TE baffle and absorber prior to final assembly. The flanged metal cylinder to which the absorber assembly is attached is the bottom portion of the standpipe which is shown bolted to the top of the vacuum chamber in Fig. 2. Electrical connections are made by a nine-pin feed-through in the base of this standpipe.

In each of the three absorbers a thermistor was used to detect the temperature change of the absorber. The thermistors used were the bead type with a mass of approximately 0.01 g and nominal resistance of 100,000 ohms at 25°C. In the Al absorber the thermistor was imbedded in the lid; in the C absorber it was imbedded in the side wall; and in the TE absorber it was in a hole passing through the center of the absorber. In all thermistor installations, a drop of vacuum pump oil was placed on the bead to improve thermal contact with the absorber material.

Detection, Amplification, and Calibration Systems

Figure 4 is a diagram of the Wheatstone bridge circuit used for detecting resistance changes in the thermistors. The battery E is a 1.34-volt mercury cell. R_1 is the thermistor; R_2 is a variable resistance made up of components giving a range from 50,000 to 160,000 ohms in 0.1-ohm steps; and R_3 and R_4 are 100,000-ohm fixed resistors. The bridge signal was amplified by a Beckman Model 14 DC breaker amplifier and was recorded by a Varian Model G-10 100-mv strip recorder with an accuracy of 1 percent of full scale. The attenuator between amplifier and recorder was a simple potentiometer introduced to insure that amplifier output is greater than 0.5 volt for full scale recorder deflection--a precaution recommended by the manufacturer of the amplifier to minimize noise originating after the gain control.

The electrical power used for calibration purposes was supplied by two 1.34-volt mercury cells in series. Current was controlled by
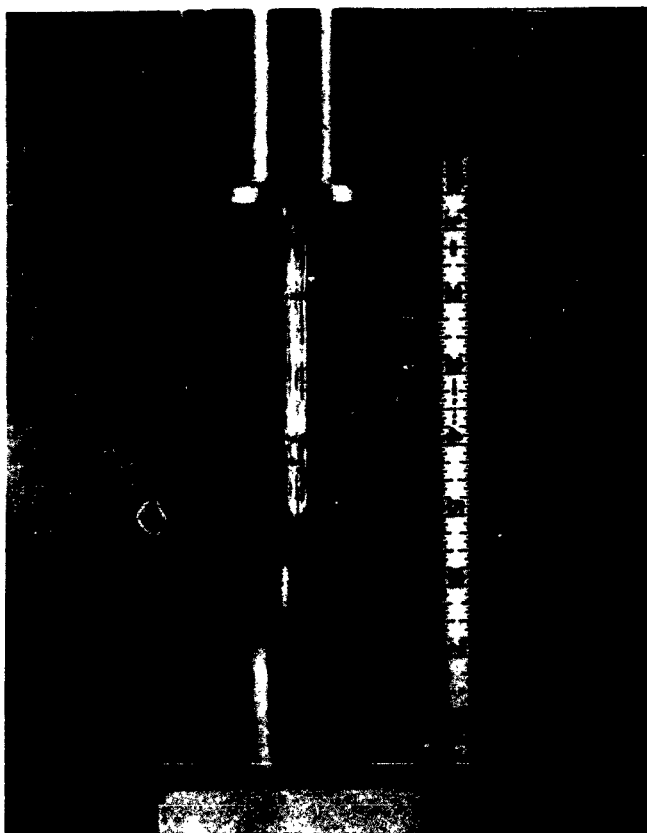
Fig. 3 The TE absorber and baffle prior to final assembly.
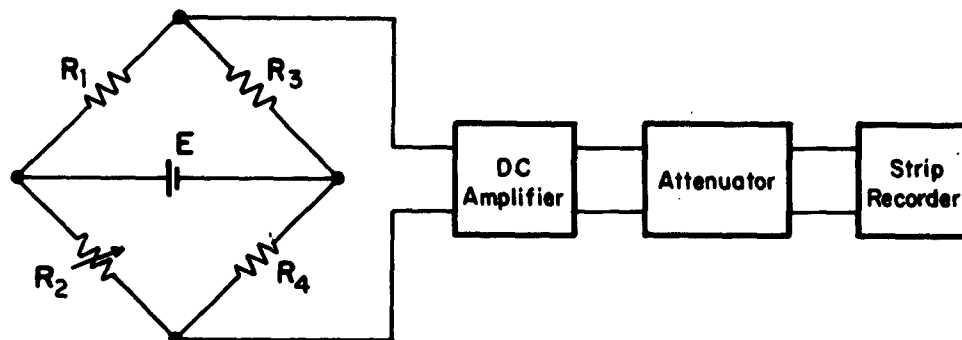
Fig. 4   The Wheatstone bridge circuit. See the text for explanation of symbols.

variable resistances in series with the heating coils and measured by a variable scale microammeter with an accuracy of 0.5 percent of full-scale deflection. Calculations of power dissipation in all heating coils was by the I^2R method with the coil resistance measured to an accuracy of 0.3 percent by a Wheatstone bridge. In the case of the TE absorber, the resistivity of the material was found to vary with current; thus power calculations required measurement of voltage drop across the absorber. This was done to an accuracy of approximately 0.5 percent by a digital voltmeter. All electronic components of the bridge and power supply were contained in a styrofoam-insulated metal box except for the amplifier, recorder, and meters.

ABSORBED DOSE DETERMINATIONS

The recorder deflection resulting from the thermistor temperature increase which occurs when energy is absorbed by the absorber, is a function of the amount of energy absorbed. Or, if time is considered,

the slope of the recorder trace is a function of the rate of energy absorption. Figure 5 shows the response trace of the recorder for a typical 10-min radiation exposure and outlines the method used to calculate the absorbed dose from the slope (or deflection rate) of the trace, taking into consideration the background drift during the period of energy absorption. The calibration factor which is used in this calculation is obtained by observing the deflection which occurs when a known quantity of electrical energy (expressed in rads in Fig. 5) is supplied to the heating coil of the same absorber, drift corrections to the recorder trace being made in the same manner as in the exposure runs.

The general procedure was to alternate calibration runs of 10 min duration with exposure runs of the same time period. Before each run the bridge was rebalanced (and the recorder thus reset) by adjusting the variable resistance in the bridge circuit. A ratio of divisions of recorder deflection per ohm change in thermistor resistance was obtained from this adjustment and was used as a sensitivity check of the system. The mean of the calibration factors obtained in individual runs was then used for each of the absorbed dose calculations. Table 2 lists these mean calibration factors and related data for the three absorbers.

In the exposures to the 900-Mev alpha particle beam the absorbed dose rates were much higher (up to 4000 rads/min) and the exposure times were accordingly reduced to limit the total absorbed energy to 4000 rads in any one run. The system sensitivity, as controlled by amplifier gain, was of course greatly reduced for these higher dose rates. Because of limited time, the number of calibration runs was held to a minimum. The calibration factor (rads/div) shown in Table 2 was therefore expressed in a more general form by taking the product of it and its corresponding systems sensitivity (div/ohm). This product is a factor (rads/ohm) which for a given thermistor resistance should be independent of system sensitivity and was found to be so by check calibrations at several different absorbed energy rate levels up to the equivalent of 4000 rads/min. It was thus used in the high dose rate experiments instead of a separately determined calibration value for each new dose rate.

The following sections describe the microcalorimeter exposures to gamma rays, fast neutrons, and 900-Mev alpha particles, and the resulting dose measurements.

Calculations

Avg Drift = $\frac{0.90 + 0.40}{2}$ = 0.65 Div/Min

Observed Deflection Rate = $\frac{68.0 - 5.8}{10}$ = 6.22 Div/Min

Corrected Deflection Rate = 6.22 − 0.65 = 5.57 Div/Min

Calibration Factor (from earlier calib. run) = 1.43 Rads/Div

Absorbed Dose Rate = 5.57 × 1.43 = 8.0 Rads/Min

Drift Before +0.90 Div/min

Deflection for a 2 − ohm change in balancing R (Calculated sensitivity 278 div/Ω)

START EXPOSURE (Chart Reading 5.8)

Drift After +0.40 Div/Min

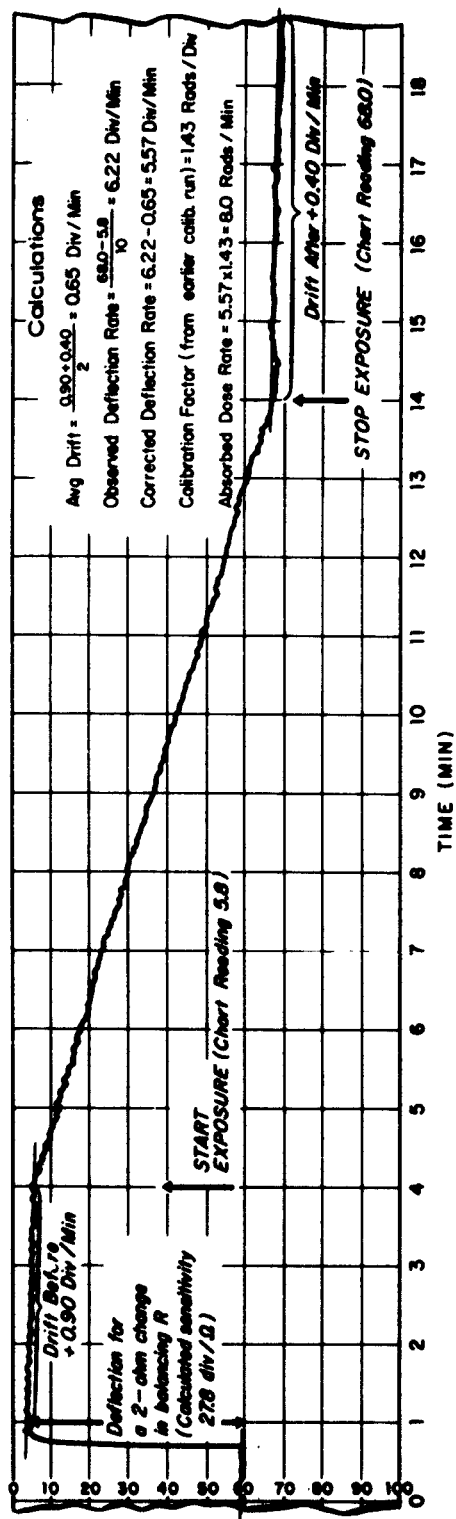STOP EXPOSURE (Chart Reading 68.0)

TIME (MIN)

Fig. 5 A typical recorder trace and calculation of the absorbed dose rate for a radiation exposure. For simplification the unit markings on the deflection scale have been omitted.

Table 2

Microcalorimeter Calibration Data

Power input (I^2R or EI):   2 to 13 µw
Calibration rate: 2 to 12 rads/min
System sensitivity: 25 to 29 div/ohm

Absorber	Temp (°C)	Thermistor Resistance (ohms)	Thermistor Sensitivity (ohms/°C)	No. of Runs	Calibration Factor (rads/div)	Standard Error of Mean Calibration Factor (rads/div)
Al	38*	55,000*	2400*	19	1.39	0.01
Al	28	85,000	4000	8	0.91	0.01
TE	28	86,000	3900	52	1.43	0.02
C	28	87,000	3900	17	0.79	0.02

* Initial runs were made at approximately 15°C above average room
  temperature. In later runs this differential was reduced to about
  5°C. The low thermistor resistance and sensitivity are the results
  of this higher operating temperature.

Gamma Rays

Gamma-ray measurements with the microcalorimeter were made using the NRDL 200-curie Co^{60} and 120-curie Cs^{137} sources. In order to minimize scattering from the equipment, the gamma-ray beam from the cone-shaped radiation aperture in the lead shield around each source was limited to the cross-sectional area of the baffle. This was accomplished by means of an additional lead collimator with a circular opening of 7-cm diameter. The roentgen output of each source was initially calibrated to an accuracy of 2 percent with a cavity ionization chamber. This secondary standard ionization chamber was constructed and calibrated by the National Bureau of Standards (NBS) for radiations ranging in energy up to those of Co^{60} gamma rays.*
A further check on the output of the source during the exposure period was made with a Victoreen condenser r-meter calibrated by NBS. The values given in Table 3 for the source calibration were based on the cavity ionization chamber measurements which were approximately 2 percent higher than the r-meter results.

Table 3

Gamma-Ray Measurements

Source	Absorber Material	Absorber Distance (cm)	No. of Runs	Source Calibration (rads/min)	Absorber Dose Rate (rads/min)	Standard Error of Mean Absorber Dose Rate (rads/min)
Co^{60}	Al*	50	6	8.9	9.0	0.1
	Al*	55	8	7.1	7.5	0.1
	TE	55	10	8.1	8.2	0.1
	C	55	15	7.2	7.2	0.2
Cs^{137}	TE	49	8	2.2	2.5	0.2
	C	49	10	2.0	2.0	0.1

* The two series of Al runs were made two months apart.

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* Private communication.

The small dimensions of the Sievert ionization chamber[3] made it possible to insert six of them inside the hollow aluminum absorber so that the dose inside the microcalorimeter could be compared with that in air. The absorbed energy averaged over the entire absorber will be very nearly the energy absorbed at the center of the absorber mass. The Co^{60} gamma-ray dose measured with the ionization chambers inserted in the absorber in the microcalorimeter was (92 ± 1) percent of the dose measured in air. The corresponding factor for the Cs^{137} source was (87 ± 1) percent. Attenuation in the aluminum end-plate of the vacuum chamber and in the baffle accounted for most of this reduction in dose. Scattering from the bath solution contributed about 1 percent to the total absorbed dose for the Co^{60} gamma rays. The lead collimator used with the Co source scattered an additional 1 percent into the gamma-ray beam while the one used with the Cs source reduced the beam intensity by approximately 1/2 percent by absorbing some of the gamma rays previously scattered into the beam from the aperture.

As all three absorbers had about the same average thickness in g/cm^2, the Sievert chamber measurements in the Al absorber and cylinder were also used to correct the C and TE absorbers. A low value for the effective absorption coefficient was observed from the measurements, 2 percent correction for attenuation in the Al absorber for both sources plus 1 percent in the baffle for the Cs^{137} gamma rays. No effect could be detected for the aluminum baffle exposed to Co^{60} gamma rays. These measurements indicate that the contribution of the scattered radiation in the baffle and absorber to the measured dose inside them was sufficient to lower the effective absorption coefficient from the Compton value (about 0.03 cm^2/g) to approximately 0.02 cm^2/g.

The results of the gamma-ray exposures are tabulated in Table 3. Source measurements in roentgens were converted to absorbed-dose calibration values in rads using 85, 88, and 97 ergs/g per roentgen for Al, C, and TE material respectively.[4] These conversion factors are based on a value of 34 ev per ion pair (W). Absorbed doses ranged from a minimum of 20 rads for the Cs^{137} source to a maximum of 90 rads for the Co^{60} source. The Cs exposures were at an absorbed dose rate of 2 rads/min, a value which represents the minimum dose rate for which the microcalorimeter was designed. Laughlin[5] reports that about 2 percent of the gamma-ray energy absorbed in conducting plastic is not converted to heat energy but is lost in endothermic chemical reactions. The TE absorber dose rate values given in Table 3 have therefore been increased by that amount as have the TE absorbed dose measurements made with the microcalorimeter for the other sources of radiation energy.

Neutrons

In order to minimize scattering from the bath solution, measurement of fast neutron absorbed dose with the microcalorimeter is limited to sources of sufficiently low average energy to allow collimation. In addition the neutron intensity has to be high enough so that the energy absorbed by a small amount of material can be determined. Neutrons from the University of California 60-in. cyclotron at Crocker Laboratory satisfied these requirements. The spectrum produced when 12-Mev protons bombard a thick Be target is similar to that of fission neutrons. Tochilin and Kohler determined the spectrum and dose rate for the fast neutrons with nuclear track plates and sulfur threshold detectors calibrated to 14.1-Mev neutrons.[6] At a beam current of 60 μa an output of 30 rads/min was obtained 30 in. from the target (NRDL value).

Neutron intercomparisons have been made at the 60-in. cyclotron between this Laboratory and the Radiobiological Research Unit, Medical Research Council (MRC), Harwell, England. The MRC measurements were made with a system of homogeneous ionization chambers which in turn had previously been used for fast neutron intercomparisons with other laboratories in the United States.[7] The NRDL neutron dose was 9 percent higher than the MRC value when the ionization chambers were calibrated with the NRDL Co[60] gamma-ray source.[8] This difference decreased to 5 percent when the calibration factor based on the MRC radium gamma-ray standard was applied to the ionization chamber readings. The discrepancy between the two gamma-ray standards has not been resolved.

The over-all size of the microcalorimeter necessitated operating it at a 40-deg angle to the direction of the incident protons with the absorber located 112 cm from the target. A collimating opening of 6-cm diameter defined the neutron beam. Neutrons outside the collimator were attenuated through 60 cm of water and 10 cm of lead. The neutron dose at the location of the absorber in the microcalorimeter was measured with four Sievert ionization chambers whose neutron response was determined at the cyclotron using the NRDL calibration value for 0 deg to the beam axis. These chambers were made neutron sensitive by replacing the standard chamber lining with a conducting plastic formulated to be tissue equivalent for both neutrons and gamma rays.[9] Ionization chamber response to gamma rays was measured with the 200-curie Co[60] source previously described. The relative neutron to gamma-ray response of the four chambers was 0.72. However, experiments at the cyclotron with an essentially tissue-equivalent chamber gave only a slightly higher response. Under the same experimental conditions, the neutron to gamma-ray response was 0.74 for 25 Sievert chambers constructed by the Naval Medical Research Institute, Bethesda, Maryland, in which all aluminum parts were replaced by conducting plastic and the

chambers filled with tissue-equivalent gas instead of air.[*]

Since the Sievert chambers did not rigidly adhere to the Bragg-Gray principle, a possibility exists that their neutron sensitivity could change with energy. Nuclear track plate measurements at 0 deg and at 45 deg to the beam axis made for an earlier experiment at the cyclotron have established that virtually no change in neutron spectrum takes place at the two geometrical locations.[10] The chamber calibration at 0 deg can therefore be expected to be valid at 40 deg to the beam axis where the microcalorimeter measurements were made.

Inasmuch as fast neutrons from the cyclotron are accompanied by some gamma radiation, it became necessary to evaluate the contribution of this component to the total absorbed dose measured by the micro-calorimeter. The gamma-ray dose was measured with dosimeter films.[11,12] A correction of 1 percent was applied for the dosage sensitivity of film to a fission-type neutron spectrum when compared to a Co^{60} calibration with gamma rays. A correction of less than 0.5 percent was also determined for the thermal neutron flux measurement obtained from gold foil activation.

Ionization chamber and film measurements were made at the location of the TE absorber with and without the presence of the microcalorimeter. The data are presented in Table 4. The doses were referenced to neutron activation of sulfur monitors placed in the center of the beam as it emerged from the collimator. Gamma rays initially accounted for 8 percent of the total dose. When identical measurements were made inside the calorimeter the gamma-ray contribution was 11 percent. This 3 percent increase was primarily from gamma rays created by thermal neutron capture of moderated fast neutrons in the ethylene glycol bath directly behind the absorber. At the same time the neutron dose at the location of the absorber was observed to decrease by 2 percent because of attenuation in the aluminum end-plate of the vacuum chamber. The neutron attenuation factor for the TE material was approximately 10 percent/cm, resulting in a correction of 8 percent for the TE absorber. The thirteen 10-min runs made with the microcalorimeter at the cyclotron resulted in doses that ranged from 24 to 50 rads and averaged 35.7 rads as determined by the sulfur monitors. After making a 2 percent allowance for endothermic chemical reactions, the same 13 runs averaged 37.6 rads of energy absorbed in the microcalorimeter.

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[*] Unpublished data.

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Table 4

Neutron Measurements

Detector	Neutron Plus Gamma-Ray Dose (rads)	Remarks
IONIZATION CHAMBERS AND FILM		
without microcalorimeter	38.4	Measurement made at the location of the TE absorber without the presence of the microcalorimeter, 92 percent neutrons
in microcalorimeter	38.8	Measurement made in the microcalorimeter with film and ionization chambers replacing the TE absorber, 89 percent neutrons
in microcalorimeter	35.7	Value calculated to include 8 percent neutron attenuation in the TE material, 88 percent neutrons
MICROCALORIMETER		
TE absorber (mean value)	37.6	
Standard error (13 runs)	0.7	

900-Mev Alpha Particles

The response of the microcalorimeter to 900-Mev alpha particles was investigated at the University of California 184-in. synchrocyclotron at Lawrence Radiation Laboratory (UCLRL). A comprehensive program of particle beam dosimetry has been developed at the cyclotron for radiobiology and medical radiology investigations.[13]

Runs were made with the alpha particle beam entering the exposure area through a collimating pipe of 1.75-in. diameter. An ionization chamber with plane-parallel electrodes was centered in the beam directly behind the collimator. The calorimeter was, in turn, aligned in the beam directly behind the chamber. The collection volume of the ionization chamber, defined by the circular area of the collecting electrode, limited dose measurements to a 0.5-in. diameter in the central region of the beam. In contrast, the area intercepted by the TE absorber was 2.4 times greater. Film dosimeters were used to check the alignment of the absorber and the radiation contours over the region of interest. Such measurements determined that the average dose received by the TE absorber was 10 percent less than that intercepted by the ion chamber.

In an attempt to check any possible ion chamber dose rate dependency produced by columnar recombination of the alpha beam, exposures were made at five dose rates ranging from 75 to 4000 rads/min. The ion chamber current was integrated over each run to give the total dose delivered in tissue rads. Results of the experiment are given in Table 5.

Table 5
900-Mev Alpha Particle Measurements

No. of Runs	Approximate Dose Rate (rads/min)	Average Dose NRDL (rads)	Dose UCLRL (rads)	NRDL/UCLRL
3	75	203	198	1.03
3	190	216	198	1.09
4	75	380	396	0.96
6	250	400	396	1.01
6	750	380	396	0.96
3	750	1480	1580	0.94
3	750	3000	3160	0.95
3	4000	3100	3160	0.98

DISCUSSION OF RESULTS

The accuracies of the calibration instrumentation and of the recorder itself combine to give an estimated value of 1 percent for the theoretical accuracy of the microcalorimeter. It will be noted in Table 2 that at the minimum dose measurements (2 rads/min for 10 min) the standard errors are significantly greater than this theoretical accuracy. The lack of reproducibility on consecutive runs which leads to the standard error is believed to result from electrical noise superimposed on the recorder traces, uncertainties in evaluating the traces, and random departures from steady-state thermal conditions in the calorimeter. Under favorable operating conditions, the latter factor makes the greatest contribution toward the standard error. This conclusion is based on the observed heat leakage rate of 4×10^{-5} cal/sec per $^{\circ}$C between the C absorber and the bath. Using this transfer rate and the known 3.6-gm mass of the C absorber it follows that a temperature differential of 0.007°C between bath and absorber will produce the same rate of temperature change in the absorber as an absorbed dose rate of 2 rads/min. Since this 0.007°C temperature differential is of the same order of magnitude as the amplitude of the bath cycle it is concluded that the dose rate of 2 rads/min represents the lower limit of the working range of the microcalorimeter.

The Co^{60} gamma-ray measurements (Table 3) were made under the most favorable operating conditions. Room temperatures were very stable and there was a minimum of interfering electronic noise. Except for the second series of aluminum runs, the agreement between source calibration values and the absorbed dose rate is within the standard error. The Cs^{137} measurements were also made under the same operating conditions but at the lower limit of the working range of the instrument, 2 rads/min. The results obtained were consistent with the standard error and the 2 percent source calibration error. The agreement between the source calibrations and the microcalorimeter measurements for the two gamma-ray energies confirm the W value of 34 ev per ion pair in air used to convert the roentgen doses to absorbed doses.

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The neutron measurements (Table 4) were made in a building in which there were large temperature fluctuations and some electrical noise interference. Nevertheless, at an exposure dose rate of approximately 4 rads/min, the standard error of only 1.9 percent of the mean absorbed dose value compares favorably with that obtained for the gamma rays. It will be noted that the difference between the microcalorimeter and ionization chamber-film measurement is greater than the standard error. Part of the discrepancy is probably inherent in the problem of comparing absorbed dose with first collision dose. After calibrating the Sievert ionization chambers on the basis of the first collision NRDL value, they were used to determine the fast neutron dose inside the microcalorimeter for the larger cross-sectional area of the TE absorber. The discrepancy between the microcalorimeter value and the MRC measurement at the 60-in. cyclotron is slightly larger. The ionization chamber-film measurements were based on the NRDL calibration value which, as previously mentioned, was 5-9 percent higher than the MRC measurement. The microcalorimeter absorbed dose value which is 5 percent higher than the NRDL calibration value thus becomes 10-14 percent higher than the MRC measurement.

During the 900-Mev alpha particle measurements (Table 5) a great deal of difficulty was experienced in the instrumentation of the temperature sensing system of the microcalorimeter. Random excursions of magnitudes several times the drift correction were frequently observed in the amplified signal from the bridge. As a result, the agreement between absorbed dose measurements in consecutive runs was not as good as might be expected for operation at the relatively low sensitivities required for these high dose rates. The values which are shown are not believed wholly representative of the capability of the microcalorimeter, but since it was not feasible to repeat the measurements, they have been included in this report. The tissue-equivalent rad dose from the high-energy alpha-particle beam was measured as it passed through the ionization chamber before reaching the absorber. There was a negligible amount of scattering of alpha particles out of the well-collimated beam. Thus the microcalorimeter and the ionization chamber measurements for the 900-Mev alpha-particle beam are directly comparable.

CONCLUSIONS

The results of the experiments discussed in this report indicate
that with the proper selection of absorber material the microcalorimeter
can be used to make absolute measurements of absorbed dose from gamma
rays, neutrons, and charged particles at rates ranging from 2 to 4000
rads/min. The principal disadvantages of its use are its large physical
size, the relatively long period of time (at least 24 hr) required for
evacuation of the chamber and the attainment of thermal equilibrium,
and the necessity for providing a cooling period after several con-
secutive exposures to permit the absorber and baffle to regain temper-
ature equilibrium with the bath. Within the limitations mentioned
above, use of the microcalorimeter as a laboratory standard has been
demonstrated.

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   CALORIMETRIC MEASUREMENTS OF GAMMA RAY,
FAST NEUTRON, AND CHARGED PARTICLE ABSORBED
DOSES by E. R. Schleiger, N. Goldstein and E.
Tochilin 28 January 1963   31 p. tables illus.
13 refs.   UNCLASSIFIED
   The energy absorbed by aluminum, carbon, or tissue-
equivalent (TE) material when exposed to gamma rays,
fast neutrons, or 900-Mev alpha particles was measured
with a microcalorimeter. The instru-
ment was patterned after the one de-
scribed by Reid and Johns, Rad. Res.
14, 1 (1961), but has an ethylene
glycol bath instead of water. Spaced
mylar sheets about 6-1/2 in. in   (over)

1. Calorimeters.
2. Fast neutrons.
3. Gamma rays.
4. Alpha particles.
5. Dose rate.

I.   Schleiger, E. R.
II. Goldstein, N.
III. Tochilin, E.
IV. Title.

diameter were mounted on one side of the absorber inside the evacuated cylindri-
cal chamber in order that the detector could be thermally insulated in the direc-
tion of the beam without the presence of bath solution.
   Gamma-ray absorbed dose rates as low as 2 rads/min were measured with the
instrument. The dose rates obtained from the exposures to Co^{60} and Cs^{137} sources
at this Laboratory (NRDL) agreed with the output of the sources as measured with a
National Bureau of Standards secondary standard cavity ionization chamber. Thir-
teen 10-min exposures of the TE absorber in the microcalorimeter to fast neutrons
from the University of California 60-in. cyclotron at Crocker Laboratory resulted
in absorbed dose measurements varying from 24 to 40 rads. The average absorbed
dose value was 5 percent higher than the NRDL determination based on flux and
spectrum measurements. Microcalorimeter exposures to the 900-Mev alpha par-
ticle beam from the University of California 184-in. synchro-cyclotron at Lawrence
Radiation Laboratory gave absorbed doses that agreed reasonably well with ioniza-
tion chamber determinations.